§22. Cryogenic Tensile Fatigue Strength of Composite Insulation Systems for Superconducting Magnets

Shindo, Y., Horiguchi, K., Narita, F. (Dept. of Mater. Processing, Graduate School of Engineering, Tohoku Univ.), Sanada, K. (Dept. of Mechanical Systems Engineering, Faculty of Engineering, Toyama Prefectural Univ.),
Nishimura, A., Tamura, H.

1. Purpose

Applications of fiber reinforced polymer (FRP) composites are rapidly expanding in cryogenic environments. To achieve thermal and electrical insulation as well as adequate structural support, woven glass fiber reinforced polymer (GFRP) laminates are used in superconducting magnets. In order to apply woven GFRP laminates to superconducting fusion magnets, long-term efficiency and reliability of GFRP composite materials need to be characterized. The fatigue behavior and damage mechanisms of GFRP materials have been actively researched by material engineers/scientists.

The test procedure ASTM (American Society for Testing and Materials) D 3479 was written to generate polymer matrix composite fatigue properties under ambient temperature conditions. However, when this procedure is applied to woven GFRP laminates at cryogenic temperatures, it is necessary to use a specimen of a certain configuration. This work is a continuation of a series of experimental studies on the cryogenic mechanical properties of woven GFRP laminates subjected to tensile loading conditions[1]. The objective of the present study is to investigate the tension-tension fatigue behavior of woven GFRP laminates at cryogenic temperatures[2].

2. Procedure

The material, investigated in this study, was National Electrical Manufacture's Association (NEMA) grade G-11 woven-fabric glass/epoxy laminates manufactured by Arisawa Mfg. Co., Ltd., Japan (EL-762H). The material is comprised of bisphenol-A epoxy resin with E-glass reinforcement.

Fatigue tests were conducted under sinusoidal load control at stress ratio R (= $\sigma_{min}/\sigma_{max}$) = 0.1 and at different maximum stress ratios S_{max} (=$\sigma_{max}/\sigma_{ult}$). The maximum and minimum applied stresses are σ_{max} and σ_{min}, respectively, and σ_{ult} is the ultimate tensile strength. Tests ran at room temperature for loading frequency 4 Hz up to 10^6 cycles, and at cryogenic temperatures for loading frequency 4 Hz up to 10^5. At cryogenic temperatures, the loading frequency was increased from 4 to 10 Hz when the failure would not occur.

3. Results

(1) Fig. 1 shows the *S-N* curves for G-11 woven-fabric glass/epoxy laminates at room temperature (R.T.), 77 K and 4 K at R = 0.1 as a plot of maximum applied stress (σ_{max}) versus number of cycles to failure (N_f). The data points with arrows, in this figure, show that specimens did not fail up to 1 million cycles which was set as the fatigue limit in this study. The observed *S-N* curves showed the usual trend that as the maximum applied stress σ_{max} increases, the fatigue life decreases. The 10^6-cycle fatigue limits at cryogenic temperatures were considerably lower than the knee stresses reported from monotonic tensile test data. (2) Failure modes at room temperature featured a macroscopically flat fracture surface. At the cryogenic temperatures, however, delaminations appeared. (3) The damage development in the fatigued specimens was primarily in the form of matrix microcracks on the specimen surface and matrix failure in the fiber bundles oriented transverse to the load direction.

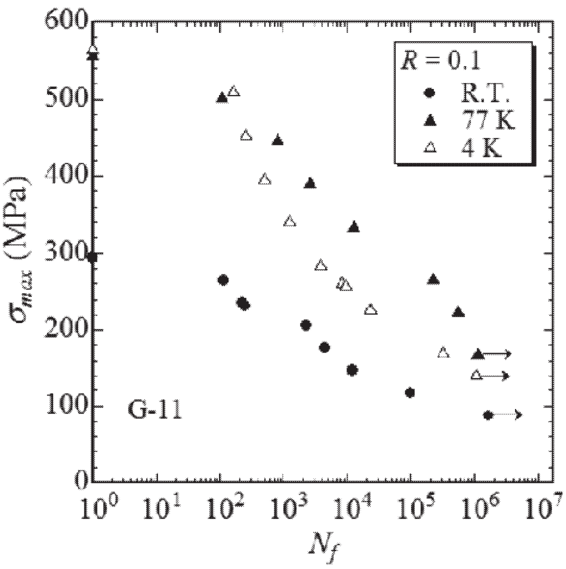

Fig. 1 S-N curves for G-11 woven-fabric glass/epoxy laminates at room temperature (R.T.), 77 and 4 K.

References

1) Shindo, Y. Takano, S., Narita, F. and Horiguchi, K.: Mech. Adv. Mater. Struct., in press.
2) Shindo, Y. Takano, S., Horiguchi, K. and Sato, T.: Cryogenics 46 (2006) 794.